Astronomy(Annual Report(from April 2003 to March 2004))

Astronomy

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Research Activites

(I). Stars and Cicumustellar Matter: Theory and Observation

1. *Surface r-Modes and Burst Oscillations of Neutron Stars.* Lee, U., ApJ, 600, 914-926,2004, Jan.

The r-modes propagating in steadily mass accreting, nuclear burning, and geometrically thin envelopes on the surface of rotating neutron stars are calculated for the envelope models that are fully radiaitive or have a convective region. We find that the fundamental r-modes in the convective models are destabilized by strong nuclear burning in the convective region. We also find that the relative frequency change $f = -(\sigma_{conv} - \sigma_{rad})/\sigma_{rad}$ is always positive and becomes less than $\sim$0.01 for the fundamental r-modes of $l' > |m| + 1$ at $|\sigma_{rad}|/2\pi$ $\sim$300Hz for $m = 1$ or at $|\sigma_{rad}|/2\pi$ $\sim$600Hz for $m = 2$, consistent with observed frequency evolution found in X-ray bursts in LMXB's.

2. *Inertial modes of neutron stars with a superfluid core.* Yoshida Shijun, and Lee Umin, MNRAS, 344, 207-222, 2003, Sep.

We investigate the modal properties of inertial modes of rotating neutron stars with a core filled with neutron and proton superfluids, taking account of entrainment effects between the superfluids. Inertial modes of rotating neutron stars with a superfluid core are split into two families; ordinary fluid inertial modes (i^o-modes) and superfluid inertial modes (i^s-modes). Since the radiation-driven instability associated with the current multipole radiation is quite weak for the inertial modes and the mutual friction damping in the superfluid core is strong, the instability caused by the inertial modes will be easily suppressed unless the entrainment parameter η is extremely small and the mutual friction damping is sufficiently weak.

3. *r-modes in relativistic superfluid stars.* Yoshida, Shijun, and Lee, Umin , Physical Review D, vol. 67, Issue 12, id. 124019, 2003, Jun.

The modal properties of the r-modes of relativistic superfluid neutron stars are discussed, taking account of the entrainment effects between proton and neutron superfluids. The r modes of a relativistic superfluid star are split into two families: ordinary fluid-like r modes (r^o mode) and superfluid-like r modes (r^s mode). The two superfluids counter-move for the r^s modes, while they co-move for the r^o modes. It is also found that the radiation driven instability due to the r^s modes is much weaker than that of the r^o modes because the matter current associated with the axial parity perturbations almost completely vanishes.

4. *Viscosity-driven Winds from Magnetized Accretion Disks.* Maruta, Daizo; Kaburaki, Osamu, The Astrophysical Journal, Volume 593, Issue 1, pp. 85-95. (2003)

We present an analytic model in which an inefficiently radiating accretion disk drives an upward wind from its surfaces. The accretion process is controlled simultaneously by a global magnetic field penetrating the disk and by the viscosity of the accreting plasma. It is shown that energy is transported radially outward within the accreting flow, associated with the viscous angular momentum transport in the same direction, and that this addition of energy from the inner region to the disk enables the latter to drive an upward wind. The parameter that specifies the strength of the wind is determined uniquely in terms of a naturally introduced viscosity parameter.

5. *Polarized $H\alpha$ Wings in the Symbiotic Stars AG Draconis and Z Andromedae.* Y. Ikeda, H. Akitaya, K. Matsuda, K. Homma, M. Seki, K.S.Kawabata, R. Hirata, and A. Okazaki. Astrophys. J. 604 357-361(2004).

We carried out polarimetric observations of two symbiotic stars, AG Dra and Z And, using the Line Polarimeter and Spectrograph (LIPS), a high-resolution echelle spectropolarimeter. We obtained the intrinsic polarization profiles with a broad wing in $H\alpha$ for both symbiotics. Based on statistical analysis, we argue that the polarization profile of AG Dra is due to Raman scattering of $Ly\beta$, because the characteristics of the polarization $H\alpha$ profile agrees well with those of the Raman λ6830 line.

(II) Galaxies: Theory

1. *Direct Mapping of Massive Compact Objects in Extragalactic Dark Halos.* Inoue, K. T., Chiba, M. 2003, ApJ, 591, L83–L86.

A significant fraction of nonbaryonic or baryonic dark matter in galactic halos may consist of massive compact objects (MASCOs) with mass $M = 10^1 - 10^4\ M_\odot$. Possible candidates for such compact objects include primordial black holes or remnants of primordial (Pop. III) stars. We propose a method for directly detecting MASCOs in extragalactic halos, using the VLBI techniques with extremely high resolution that would be achieved by the next-generation mission of the VLBI Space Observatory Program such as VSOP-2. If a galactic halo comprising a large number of MASCOs produces multiple images of a background radio-loud QSO by gravitational lensing, then a high-resolution radio map of each macrolensed image should reveal microlensing effects by MASCOs. To assess their observational feasibility, we simulate microlensing of the radio-loud, four-image lensed QSO, B1422+231, assuming angular resolution of ~ 0.01 mas. We find that the surface brightness of the macrolensed images shows distinct spatial patterns on the scale of the Einstein radius of the perturbers. Many tiny dark spots also appear in the macrolensed images associated with a decrease in the surface brightness toward the fringe of the original QSO image. Because such spatial patterns in each macrolensed image cannot be linearly mapped to those in other macrolensed images, it is fairly easy to discriminate them from intrinsic substructures within a QSO. Based on the size, position, and magnified or demagnified patterns of images, we shall be able to determine the mass and density profile of an individual MASCO as well as its spatial distribution and abundance in a galactic halo.

2. *Kinematics of tidal debris from omega Centauri's progenitor galaxy.* Mizutani, A., Chiba, M., Sakamoto, T. 2003, ApJ, 589, L89–92.

We present the kinematic properties of a tidally disrupted dwarf galaxy in the Milky Way, based on the hypothesis that its central part once contained the most massive Galactic globular cluster, ω Cen. Dynamical evolution of a self-gravitating progenitor galaxy that follows the present-day and likely past orbits of ω Cen is calculated numerically and the kinematic nature of their tidal debris is analyzed, combined with randomly generated stars comprising spheroidal halo and flat disk components. We show that the retrograde rotation of the debris stars at ~ -100 km s^{-1} accords with a recently discovered, large radial velocity stream at ~ 300 km s^{-1} towards the Galactic longitude of $\sim 270°$. These stars also contribute, only in part, to a reported retrograde motion of the outer halo at the North Galactic Pole. The prospects for future debris searches and the implications for the early evolution of the Galaxy are briefly presented.

3. *The mass of the Milky Way: Limits from a newly assembled set of halo*

objects. Sakamoto, T., Chiba, M., Beers, T. C. 2003 A&A, 397, 899–911.

We set new limits on the mass of the Milky Way, making use of the latest kinematic information for Galactic satellites and halo objects. Our sample consists of 11 satellite galaxies, 137 globular clusters, and 413 field horizontal-branch (FHB) stars at large distances from the sun. Roughly half of the objects in this sample have measured proper motions, permitting the use of their full space motions in our analysis. We adopt a Bayesian likelihood approach to reproduce the observed distribution of the current positions and motions of the sample, in a prescribed Galactic potential giving a flat rotation curve. This method enables a search for the most likely total mass of the Galaxy, without suffering a large influence in the final result due to the presence or absence of Leo I. Although the best mass estimate depends somewhat on the model assumptions, such as the unknown prior probabilities for the model parameters, the resultant systematic change in the mass estimate is confined to a relatively narrow range of a few times $10^{11} M_{\odot}$ owing to our consideration of many FHB stars. The most likely total mass derived from this method is $2.5^{+0.5}_{-1.0} \times 10^{12}\ M_{\odot}$ (including Leo I), and $1.8^{+0.4}_{-0.7} \times 10^{12}\ M_{\odot}$ (excluding Leo I). The mass estimate within the distance to the Large Magellanic Cloud ($\sim$ 50 kpc) is essentially independent of the model parameters, yielding $5.5^{+0.0}_{-0.2} \times 10^{11}\ M_{\odot}$ (including Leo I) and $5.4^{+0.1}_{-0.4} \times 10^{11}\ M_{\odot}$ (excluding Leo I). Implications for the origin of halo microlensing events and prospects for more accurate estimates of the total mass are also discussed.

4. *Galaxy threshing and the origin of ultra-compact dwarf galaxies in the Fornax cluster.* Bekki, K.; Couch, W. J.; Drinkwater, M. J.; Shioya, Y. , Monthly Notice of the Royal Astronomical Society, Volume 344, Issue 2, pp. 399-411 (2003)

A recent all-object spectroscopic survey centred on the Fornax cluster of galaxies has discovered a population of subluminous and extremely compact members, called 'ultra-compact dwarf' (UCD) galaxies. In order to clarify the origin of these objects, we have used self-consistent numerical simulations to study the dynamical evolution a nucleated dwarf galaxy would undergo if orbiting the centre of the Fornax cluster and suffering from its strong tidal gravitational field. We find that the outer stellar components of a nucleated dwarf are removed by the strong tidal field of the cluster, whereas the nucleus manages to survive as a result of its initially compact nature. The developed naked nucleus is found to have physical properties (e.g. size and mass) similar to those observed for UCDs. We also find that although this formation process does not have a strong dependence on the initial total luminosity of the nucleated dwarf, it does depend on the radial density profile

of the dark halo in the sense that UCDs are less likely to be formed from dwarfs embedded in dark matter haloes with central 'cuspy' density profiles. Our simulations also suggest that very massive and compact stellar systems can be rapidly and efficiently formed in the central regions of dwarfs through the merging of smaller star clusters. We provide some theoretical predictions on the total number and radial number density profile of UCDs in a cluster and their dependencies on cluster masses.

5. *Formation and Evolution of Red Hδ-strong Galaxies in Distant Clusters: Two Different Evolutionary Paths to S0 Galaxies?* Shioya, Yasuhiro; Bekki, Kenji; Couch, Warrick J. The Astrophysical Journal, Volume 601, Issue 2, pp. 654-665 (2004)

We numerically investigate the spectrophotometric evolution of galaxies with a variety of different star formation histories and degrees of dust extinction in order to elucidate the origin of the "red Hδ-strong" (RHDS) galaxies-characterized by strong [EW(Hδ) $>$ 3 Å] Balmer line absorption but with colors as red as the dormant E/S0 systems-first observed in distant clusters of galaxies. Specifically, we investigate the evolution in the $[(B-R)$, EW(Hδ)]-plane of two different galaxy models: a "truncation" model in which a galaxy with a declining star formation rate (typical of a normal spiral) has its star formation abruptly truncated, and a "starburst" model in which a galaxy undergoes a secondary burst of star formation that is abruptly halted. This leads to the following three main results: (1) Both models pass through the zone inhabited by the RHDS galaxies in this plane, but the "truncation" models cannot explain the most extreme cases, which have EW(Hδ)$>$ 6 Å. (2) The reddest RHDS galaxies can only be explained by "truncation" or "starburst" models that have very heavy dust extinction ($A_V > 0.5$ mag). (3) Irrespective of whether dust effects are included, the "truncation" models are incapable of reproducing the very blue ($B-R < 1.6$) analogs of the RHDS galaxies. By comparing these results with recent Hubble Space Telescope-based morphological and ground-based spectroscopic studies of distant cluster galaxies, we propose that there are two possible different evolutionary paths for the transformation of cluster spirals into S0 galaxies.

6. *Photometoric Evolution of Dusty Starburst Galaxies.* Shioya, Yasuhiro, *Studies of Galaxies in the Young Universe with New Generation Telescope*, Proceedings of Japan-German Seminar, held in Sendai, Japan, July 24-28, 2001, Eds.: N. Arimoto and W. Duschl, 2004, p. 125-128

By performing N-body simulations of chemodynamical evolution of galaxies with dusty starbursts, we investigate photometric evolution of gas-rich major mergers in order to explore the nature of ultraluminous infrared galax-

ies (ULIRGs) with the total infrared luminosity (L_{IR} for 8 $\sim$ 1000μm) of $\sim 10^{12} L_{\odot}$. Main results are the following five. (1) Global colors and absolute magnitudes the during dusty starburst of a major merger do not change with time significantly. (2) Dust extinction of stellar populations in a galaxy merger with large infrared luminosity ($L_{IR} > 10^{11} L_{\odot}$) is selective in the sense that younger stellar populations are preferentially obscured by dust than old ones. (3) L_{IR}, the ratio of L_{IR} to L_B and the dust temperature $T_{\rm dust}$ increase with the increase of the star formation rate. (4) The star formation efficiency, total gas mass, the degree of dust extinction (A_V), $T_{\rm dust}$, L_{IR}, and L_{IR}/L_B depend strongly on the separation of two cores of the merger. (5) The two-dimensional distribution of global colors (e.g., $R-K$) shows a negative color gradient during starburst. Our numerical results clearly demonstrate that dynamical processes of major galaxy merging, which can control the time evolution of the relative spatial distribution of dusty interstellar gas and young stars, play a vital role in determining photometric properties of ULIRGs.

(III) Galaxies: Observation

1. *Iron Is Not Depleted in High-Ioniation Nuclear Emission-Line Regions of Active Galactic Nuclei.* Nagao, T., Murayama, T., Shioya, Y., & Taniguchi, Y. 2003, AJ, 125, 1729-1735

To examine whether or not high-ionization nuclear emission-line regions (HINERs) in narrow-line regions of active galactic nuclei are dusty, we focus on two high-ionization forbidden emission lines, [Fe VII]λ6087 and [Ne V]λ3426. We perform photoionization model calculations to investigate possible dependences of the flux ratio of [Fe VII]λ6087/[Ne V]λ3426 on various gas properties, in order to investigate how useful this flux ratio is to explore the dust abundances in HINERs. Based on our photoionization model calculations, we show that the observed range of the flux ratio of [Fe VII] λ6087/[Ne V] & lambda;3426 is consistent with the dust-free models, while it cannot easily be explained by the dusty models. This suggests that iron is not depleted in HINERs, which implies that the HINERs are not dusty. This result is consistent with the idea that the HINERs are located closer than the dust-sublimation radius (i.e., the inner radius of dusty tori) and thus can be hidden by dusty tori when seen from a edge-on view toward the tori, which is also suggested by the AGN-type dependence of the visibility of high-ionization emission lines.

2. *Subaru Deep Survey. IV. Discovery of a Large-Scale Structure at Redshift =5.* (Y.Shioya, Y. Taniguchi), Shimasaku, K., et al. 2003, ApJ, 586,

L111-114

We report the discovery of a large-scale structure of Ly_{α}; emitters (LAEs) at $z = 4.86$ based on wide-field imaging with the prime-focus camera (Suprime-Cam) on the Subaru Telescope. We observed a 25' $\times$ 45' area of the Subaru Deep Field in a narrow band (NB711, λ_c =7126Å), R and i'. We isolate from these data 43 LAE candidates down to NB711=25.5 mag using color criteria. Follow-up spectroscopy of five candidates suggests the contamination by low-z objects to be 20We find that the LAE candidates are clustered in an elongated region on the sky of 20 Mpc in width and 50 Mpc in length at $z = 4.86$, which is comparable in size to present-day large-scale structures. This elongated region includes a circular region of 12 Mpc radius of higher surface overdensity, which may be the progenitor of a cluster of galaxies. Assuming this circular region to be a sphere with a spatial overdensity of 2, we compare our observation with predictions by cold dark matter models. We find that an $\Omega_0 = 0.3$ flat model with $\sigma_8 = 0.9$ predicts the number of such spheres consistent with the observed number (one sphere in our survey volume) if the bias parameter of LAEs is $b \simeq 6$. This value suggests that the typical mass of dark halos hosting LAEs at $z \simeq 5$ is of the order of 1012 Msolar. Such a large mass poses an interesting question about the nature of LAEs.

3. *The H α Luminosity Function and Star Formation Rate at z 0.24 Based on Subaru Deep Imaging Data.* Fujita, S. S., Ajiki, M., Shioya, Y., Nagao, T., Murayama, T., Taniguchi, Y., Umeda, K., Yamada, F. S., Yagi, M., Okamura, S., & Komiyama, Y., 2003, ApJ, 586, L115-L118

We have carried out a deep imaging survey for Hα-emitting galaxies at $z \simeq 0.24$ using a narrowband filter tuned with the redshifted line. The total sky area covered is 706 arcmin2 within a redshift range from 0.234 to 0.252 ($\delta z = 0.018$). This corresponds to a volume of 3.9×10^3 Mpc^3. We obtain a sample of 348 Hα-emitting galaxies whose observed emission-line equivalent widths are greater than 12 Å. Using the Kennicutt relation between the H_{α}; luminosity and the star formation rate, the star formation rate density in the covered volume is estimated to be 0.036 $M_{\odot}$ yr^{-1} Mpc^{-3}. This value is higher by a factor of 3 than the local star formation rate density.

4. *The Discovery of Two Lyman α Emitters beyond Redshift 6 in the Subaru Deep Field.* (Taniguchi, Yoshiaki, Ajiki, Masaru; Fujita, Shinobu S.; Murayama, Takashi; Nagao, Tohru; Shioya, Yasunori) Kodaira, K., et al. 2003, PASJ, 55, L17-L21

We performed a deep optical imaging survey using a narrow-band filter (NB921) centered at $\lambda = 9196$Å, together with i' and z' broadband filters

covering an 814 arcmin^2 area of the Subaru Deep Field. We obtained a sample of 73 strong NB921-excess objects. We then obtained optical spectroscopy of nine objects in our NB921-excess sample, and identified at least two Ly$_\alpha$; emitters at $z = 6.541$ and $z = 6.578$, each of which shows the characteristic sharp cutoff together with continuum depression at wavelengths shortward of the line peak. The latter object is more distant than HCM-6A at $z = 6.56$, which is the most distant known object that has been found so far. These new data allow us to estimate the first meaningful lower limit of the star-formation rate density beyond redshift 6; $\rho_{\rm SFR} \simeq 5.2 \times 10^{-4}$ yr^{-1} Mpc^{-3}. Since it is expected that the actual density is several times higher than this value, our new observation reveals that a moderately high level of star formation activity already occurred at $z \simeq 6.6$.

5. *Cosmic Star Formation History Associated with Quasar Activity: An Approach Using the Black Hole-to-Bulge Mass Correlation.* Wang, Y. P., Yamada, T., & Taniguchi, Y. 2003, ApJ, 588, 113-118

The tight correlation between the masses of central black holes and their host spheroids in nearby galaxies and active galactic nuclei (AGNs) suggests that black hole growth is closely related to their spheroid formation. Based on our previous work regarding such a joint evolutionary scheme and the consequential black hole-to-bulge mass correlation, we use the X-ray luminosity function of AGN and the cosmological evolution rate, which are from ROSAT X-ray surveys, to estimate the cosmic star formation history associated with the black hole growth. By the basic assumption that the major black hole growth occurs during the luminous AGN phase, the luminosity function of AGNs as a function of redshift traces not only the accretion history of the black holes but also the cosmic star formation history of the spheroids. Although the space density of the especially luminous quasars is very low, we show that the total amount of star formation associated with the massive black hole growth is almost the same as that of Lyman break galaxies detected by the current optical deep surveys. We thus argue that the optical deep surveys may miss about half of the net star formation in our universe. This is probably due in part to significant dust extinction, as well as the small field of view of previous optical surveys, which cannot sample such rare events with relatively short timescale. However, the far-infrared emission from the dust heated by ongoing star formation during the black hole growth could sufficiently account for the observed SCUBA number counts and would be the probable dominating energy source of the SCUBA population.

6. *Orbital Motion in the Radio Galaxy 3C 66B: Evidence for a Supermassive Black Hole Binary.* Sudou, H., Iguchi, S., Murata, Y., & Taniguchi, Y.

2003, Science, 300, 1263-1265

Supermassive black hole binaries may exist in the centers of active galactic nuclei such as quasars and radio galaxies, and mergers between galaxies may result in the formation of supermassive binaries during the course of galactic evolution. Using the very-long-baseline interferometer, we imaged the radio galaxy 3C 66B at radio frequencies and found that the unresolved radio core of 3C 66B shows well-defined elliptical motions with a period of 1.05 years, which provides a direct detection of a supermassive black hole binary.

7. *Are Two $z \simeq 6$ Quasars Gravitationally Lensed ?* (Yamada, Sanae F.; Shioya, Yasuhiro; Taniguchi, Yoshiaki; Murayama, Takashi; Ajiki, Masaru; Nagao, Tohru; Fujita, Shinobu S.; Umeda, Kazuyoshi) Yamada, F. S., et al. 2003, PASJ, 55, 733-738

Several high-z ($z > 5.7$) quasars have been found during the course of Sloan Digital Sky Survey. The presence of such very high-z quasars is expected to put constraints on early structure formation. On one hand, it is suggested that these most luminous objects at high redshift are biased toward highly magnified objects by gravitational lensing. To clarify the effect of gravitational lensing on high-z quasars, we began an imaging survey of intervening lensing galaxies. Indeed, our previous optical image showed that SDSSp J104433.04 + 012502.2 at $z = 5.74$ is gravitationally magnified by a factor of 2. In this paper, we report our new optical imaging of two other high-zquasars, SDSSp J103027.10 + 052455.0 at $z = 6.28$ and SDSSp J130608.26 + 035626.3 at $z = 5.99$. Since we found neither an intervening galaxy nor a counter image with $i' > 25.4$ - 25.8 around each quasar, we conclude that they are not strongly ma gnified regardless that a lens galaxy is dusty.

8.*A deep 6.7 μm survey in the SSA13 field with ISO .* (Taniguchi, Y.) Sato, Y., et al. 2003, A&A, 405, 833-849

We present results of a deep mid-infrared survey in the SSA13 field with the Infrared Space Observatory (ISO). In order to probe the near-infrared light at high redshifts, we surveyed the field with the broad band LW2 (5-8.5 μm) filter of the mid-infrared camera ISOCAM. Adopting a highly redundant imaging strategy for the 23 h observation and carefully treating gradual changes in the detector responsivity caused by a very high rate of cosmic ray impacts, we succeeded in reaching an 80% completeness limit of 16 μJy in the central 7 arcmin^2 region. Utilizing the signal-to-noise ratio map, we detected 65 sources down to 6 μJy in the 16 arcmin^2 field. Integral galaxy number counts at 6.7 μm are then derived, reaching 1.3×10^4 deg^{-2} at the faint limit with a slope of -1.6 between 13 μJy and 130 μJy.

9. *On the Origin of Lyα Blobs at High Redshift: Kinematic Evidence of a Hyperwind Galaxy at $z = 3.1$.* (Taniguchi, Yoshiaki; Kawabata, Koji S.; Shioya, Yasuhiro; Murayama, Takashi; Nagao, Tohru) Ohyama, Y., et al. 2003, ApJ, 591, L9-L12.

We present deep optical spectroscopy of an extended Lyα emission-line blob located in an overdense region at redshift $z = 3.1$ (blob 1 of Steidel et al.). The origin of such Lyα blobs has been debated for some time; two of the most plausible models are (1) that it comes from a dust-enshrouded, extreme starburst galaxy with a large-scale galactic outflow (superwind/hyperwind) or (2) that it is the cooling radiation of protogalaxies in dark matter halos. Examination of the kinematic properties of the Lyα emission-line gas should allow us to determine its nature. With this motivation, we performed optical spectroscopy on blob 1 using the Subaru Telescope and found that its kinematic properties can be well explained in terms of superwind activity.

10. *Subaru High-Dispersion Spectroscopy of the Narrow-Line Region in the Seyfert Galaxy NGC 4151.* Nagao, T., Murayama, T., Shioya, Y., & Taniguchi, Y. 2003, AJ, 126, 1167-1182

We report on a study of the forbidden emission-line spectrum of the nearby Seyfert 1.5 galaxy NGC 4151 based on the high-resolution ($R = 45,000$) optical spectrum obtained using the High Dispersion Spectrograph on the Subaru Telescope. The profile parameters, such as the emission-line widths, velocity shifts from the recession velocity of the host galaxy, and asymmetry indexes, for emission lines, including very faint ones such as [Ar IV]4712, 4740 and [Fe VI]5631, 5677, are investigated. Statistically significant correlations between the measured profile parameters and the critical densities of transitions are found, while there are no meaningful correlations between the profile parameters and the ionization potentials of ions. By comparing the results with photoionization model calculations, we remark that a simple power-law distribution of the gas density that is independent of the radius from the nucleus cannot explain the observed correlation between the emission-line widths and the critical densities of the transitions. Taking into account the additional dense gas component expected to exist in the innermost area of the narrow-line regions, the observed correlations between the emission-line width and the critical density of the transitions can be understood since high critical density emission lines can arise at such relatively inner regions even if their ionization potentials are low. The observed correlation between the blueshift of the emission lines and the critical densities of the ions is also explained if such dense gas clouds located closer to the nucleus have larger outflowing velocities.

11. *A Subaru Search for Lyα Emitters at Redshift 5.7.* Ajiki, Masaru; Taniguchi, Yoshiaki; Fujita, Shinobu S.; Shioya, Yasuhiro; Nagao, Tohru; Murayama, Takashi; Yamada, Sanae; Umeda, Kazuyoshi; Komiyama, Yutaka 2003, AJ, 126, 2091-2107

We present the results of a survey for Lyα emitters at $z = 5.7$ based on optical narrowband (NB816), and broadband (B, RC, IC, and z') observations of the field surrounding the high-redshift quasar SDSSp J104433.04-012522.2 with the 8.2 m Subaru Telescope using the Subaru prime-focus camera, Suprime-Cam. This survey covers a sky area of 720 arcmin^2 and a comoving volume of 2×10^5 Mpc^3. We have found 20 candidate Ly$_\alpha$; emitters at $z \simeq 5.7$ with $\Delta z \simeq 0.1$. Two of them have been confirmed as star-forming galaxies at $z = 5.655$ and $z = 5.687$ from our follow-up optical spectroscopy. We discuss the star formation properties of the 20 objects from a statistical point of view.

12. *ISO deep far-infrared survey in the Lockman Hole. III. Catalogs and source counts at 90 & 170 μm .* (Taniguchi, Y.) Kawara, K., et al. 2004, A&A, 413, 843-859

We present the catalogs and source counts for the C90 (reference wavelength of 90 μm) and C160 (170 μm) bands, which were extracted from our analysis of an ISO deep far-infrared survey conducted as part of the Japan/UH ISO cosmology project. The total survey area is 0.9 deg^2 in two fields within the Lockman Hole. The source counts are derived by applying the corrections for the detection rate and flux bias. The resultant counts are quite consistent with the constraints derived from the fluctuation analysis performed in Paper II.

13. *Faint 6.7 Micron Galaxies and Their Contributions to the Stellar Mass Density in the Universe.* (Y. Taniguchi), Sato, Y., et al. 2004, AJ, 127, 1285-1304

We discuss the nature of faint 6.7 μm galaxies detected with the mid-infrared camera ISOCAM on board the Infrared Space Observatory (ISO). The 23 hr integration on the Hawaii Deep Field SSA13 has provided a sample of 65 sources down to 6 μJy at 6.7 μm. For 57 sources, optical or near-infrared counterparts were found using a statistical method. All four Chandra sources, three SCUBA sources, and one VLA/FIRST source in this field were detected at 6.7 μm with high significance. Using their optical to mid-infrared colors, we divided the 6.7 μm sample into three categories: low-redshift galaxies with past histories of rapid star formation, high-redshift ancestors of these, and other star-forming galaxies. Rapidly star-forming systems at high redshifts dominate the faintest end. Spectroscopically calibrated photometric

redshifts were derived from fits to a limited set of template spectral energy distributions (SEDs). They show a high-redshift tail in their distribution with faint galaxies at $z > 1$. The 6.7 μm galaxies tend to have brighter K magnitudes and redder I-K colors than the blue dwarf population at intermediate redshifts. Stellar masses of the 6.7 μm galaxies were estimated from their rest-frame, near-infrared luminosities. Massive galaxies were found in the redshift range of $z = 0.2$-3.

14. *Subaru Spectroscopy of the Giant Lyα Nebula Associated with the High-z Powerful Radio Galaxy 1243+036.* Ohyama, Y., & Taniguchi, Y. 2004, AJ, 127, 1313-1317

We report results of our new spatially resolved, optical spectroscopy of the giant Lyα nebula around a powerful radio galaxy, 1243+036 (4C +03.24), at $z = 3.57$. The nebula is extended over 30 kpc from the nucleus and forms a pair of cones or elongated bubbles. The high-velocity (roughly -1000 km s^{-1} blueshifted with respect to the systemic velocity) Lyα-emitting components are detected at both sides of the nucleus along its major axis. We discuss possible origins of the nebula, such as (1) a shock-heated expanding bubble or outflowing cone associated with the superwind activity of the host galaxy, (2) halo gas photoionized by the anisotropic radiation from the active galactic nuclei (AGNs), and (3) a jet-induced star formation or shock. The last possibility may not be likely because Lyα emission is distributed out of the narrow channel of the radio jet. We show that the superwind model is most plausible since it can explain both the characteristics of the morphology (size and shape) and the kinematical structures (velocity shift and line width) of the nebula although the photoionization by AGNs may contribute to the excitation to some extent.

15. *Starburst-AGN Connections from High Redshift to the Present Day .* Taniguchi, Y. 2003, The Proceedings of the IAU 8th Asian-Pacific Regional Meeting, Vol. I, 2002, ASP Conference Proceedings, Vol. 289. Edited by Satoru Ikeuchi, John Hearnshaw and Tomoyuki Hanawa., Astronomical Society of the Pacific, 2003, p. 353-362

We give a review of possible starburst-AGN (active galactic nuclei) connections from high redshift to the present day. First, we give an historical review on some basic ideas related to the starburst-AGN connection published in the literature. Secondly, we focus our attention on the so-called Magorrian relation, which is the close relationship between the nuclear black hole mass and the bulge mass, established in nearby galaxies. If the Magorrian relation is universal, we obtain an important implication that any supermassive black holes were made through successive merging processes of starburst remnants

(i.e., neutron stars and stellar-sized black holes), providing a channel for the starburst-AGN connection. Thirdly, we briefly discuss a possible new scenario for the formation of quasar nuclei at very high redshift, based on an idea that successive mergers of starburst remnants formed in sub-galactic gaseous clouds.

16. *Lymanα Emitters Beyond Redshift 5: The Dawn of Galaxy Formation.* Taniguchi, Y., Shioya, Y., Ajiki, M., Fujita, S. S., Nagao, T., & Murayama, T. 2003, JKAS, 36, 123-144

The 8m class telescopes in the ground-based optical astronomy together with help from the ultra-sharp eye of the Hubble Space Telescope have enabled us to observe forming galaxies beyond redshift $z = 5$. In particular, more than twenty Lyα-emitting galaxies have already been found at $z > 5$. These findings provide us with useful hints to investigate how galaxies formed and then evolved in the early universe. Further, detailed analysis of Lyα emission line profiles are useful in exploring the nature of the intergalactic medium because the trailing edge of cosmic reionization could be close to $z \sim$ 6-7, at which forming galaxies have been found recently. We also discuss the importance of superwinds from forming galaxies at high redshift, which has an intimate relationship between galaxies and the intergalactic medium. We then give a review of early cosmic star formation history based on recent progress in searching for Lyα-emitting young galaxies beyond redshift 5.

17. *Cosmic Star Formation History Associated with QSO Activity: An Approach by the Black Hole to Bulge Mass Correlation.* Wang, Y. P., Yamada, T., & Taniguchi, Y. 2003, The Proceedings of the IAU 8th Asian-Pacific Regional Meeting, Volume I, 2002, ASP Conference Proceedings, Vol. 289. Edited by Satoru Ikeuchi, John Hearnshaw and Tomoyuki Hanawa, Astronomical Society of the Pacific, 2003, p. 267-270

AGNs and their evolution to estimate the star formation history which is associated with the black hole growth. We show that the total amount of star formation associated with the massive black hole growth is almost the same as that detected by the current optical deep surveys. Meanwhile, the far infrared emission from the dust heated by star formation on-going during the black hole growth could sufficiently account for the observed SCUBA counts, and would be the good candidates of the SCUBA population.

18. *Radio and FIR Sources in the Lockman Hole ISOPHOT Survey Field.* (Taniguchi, Y.) Yun, M. S., et al. 2003, Galaxy Evolution: Theory & Observations (Eds. Vladimir Avila-Reese, Claudio Firmani, Carlos S. Frenk & Christine Allen), RMxAC, 17, 271-271

To investigate the nature and the evolution of optically faint, luminous infrared starburst galaxies, a deep survey of two 44×44 arcmin^2 fields in the Lockman Hole region was conducted using ISOPHOT camera on ISO at 95 and 175 μm. We present the preliminary results from our multi-wavelength investigations of the identified sources in the Lockman Hole ROSAT/XMM deep field. One or more radio sources are found at the source position in more than 80% of cases, and spectroscopic redshifts of about 50% of the sources have been obtained so far.

19. *The Mahoroba Project — Deep Survey with an Optical Intermediate-Band Filter System on the Subaru Telescope.* Taniguchi, Y., *Studies of Galaxies in the Young Universe with New Generation Telescope*, Proceedings of Japan-German Seminar, Japan, July 24-28, 2001, Eds.: N. Arimoto and W. Duschl, 2004, p. 107-111

We show a standard way to carry out the deep survey program on the Subaru 8m telescope with SUPRIME-CAM, FOCAS, OHS, IRCS, and FMOS. Special emphasis is addressed to very deep surveys with the MAHOROBA set of intermediate-band filters (R=23) and FMOS. The main purpose of the MAHOROBA survey is secret; MAHOROBA is an ancient Japanese word which means "the best place" or "the most comfortable place".

20. *Optical Identification of the ISOPHOTFIR Sources.* (Kakazu, Yuko; Murayama, Takashi; Taniguchi, Y.) Kakazu, Y., et al. 2004, *Studies of Galaxies in the Young Universe with New Generation Telescope*, Proceedings of Japan-German Seminar, held in Sendai, Japan, July 24-28, 2001, Eds.: N. Arimoto and W. Duschl, 2004, p. 129-132

We present the optical follow up observations of the ISOPHOTFIR sources found in our 175 micron deep survey in the Lockman Hole using ISOPHOT on board ISO (Kawara et al. 1998, AA, 328, L9). Optical and NIR observations were made using ESI and NIRSPEC on the Keck II, IRCS on the Subaru, the 8k mosaic CCD camera on the UH88, and VLA. We have identified optical counterparts of 35 ISOPHOT FIR sources with redshift between 0.03 and 1.6. We discuss their observational properties.

21. *Detection of Molecular Clouds in the Interarm of the Flocculent Galaxy NGC 5055.* Tosaki, Tomoka; Shioya, Yasuhiro; Kuno, Nario; Nakanishi, Kouichiro; Hasegawa, Takashi Publications of the Astronomical Society of Japan, Vol.55, No.3, pp. 605-613 (2003)

We present high-resolution ($\sim 4''$) ^{1}2CO(J = 1-0) mapping observations with high-velocity resolution ($\sim$ 2.6 km s^{-1}) toward the disk of flocculent galaxy NGC 5055, using the Nobeyama Millimeter Array in order to study

the physical properties of the molecular clouds in the arm and the interarm. The map shows clumpy structures. Although these are mainly distributed along an arm seen in NIR, some are located in the interarm. These clouds in the arm and the interarm have a typical size and mass of a few 100pc and a few 106Msolar. These correspond to the largest Giant Molecular Cloud (GMC) in our Galaxy, and are slightly smaller than Giant Molecular Associations (GMAs) in the grand design spiral M 51. Their CO flux-based masses show good agreement with their virial masses. A size-velocity dispersion relation is plotted on an extension of the relation for the Galactic GMCs. It suggest that the properties of these clouds are similar to that of the Galactic GMCs. We found no clear systematic offset between the molecular gas and H II regions unlike M 51. This and no existense of GMAs suggest that, in NGC 5055, cloud formation and star formation in the arm and the interarm are due to enhancement of gas by local fluctuation; while, in grand design spiral galaxies, such as M 51, GMA formations may occur only in the arm due to a strong density wave and enhanced star formation in GMA formation may occur. These may control the optical morphology of spiral arms in spiral galaxies.

22. *The First Data Release of the Sloan Digital Sky Surve* (Takashi Ichikawa.) Abazajian, K. et al. AJ, 126, 2081-2086

The Sloan Digital Sky Survey (SDSS) has validated and made publicly available its First Data Release. This consists of 2099 deg^{2}2 of five-band (u, g, r, i, z) imaging data, 186,240 spectra of galaxies, quasars, stars and calibrating blank sky patches selected over 1360 deg^{2}2 of this area, and tables of measured parameters from these data. The imaging data go to a depth of $r \sim 22.6$ and are photometrically and astrometrically calibrated to 2% rms and 100 mas rms per coordinate, respectively. The spectra cover the range 3800-9200 Å, with a resolution of 1800-2100. This paper describes the characteristics of the data with emphasis on improvements since the release of commissioning data (the SDSS Early Data Release) and serves as a pointer to extensive published and on-line documentation of the survey.

23. *ERO R1 in the Field of CL 0939+4713: Evidence for an S0-like Galaxy at* $z \sim 1.5$. Iye, M., Shimasaku, K., Miyazaki, S., Simpson, C., Imanishi, M., Kashikawa, N., Kodama, T., Chiba, M., Saito, Y., Goto, M., Iwamuro, F., Kobayashi, N., Okamura, S., Terada, H. 2003, ApJ, 590, 770–777.

We present further observations of the extremely red object ERO J094258+4659.2, identified earlier by Iye et al. as ERO R1 in their deep images of the cluster A851. We estimate its redshift independently by eight-band photometric redshift determination and cross-correlation of a new H-

band spectrum with the optical spectra of local E/S0 galaxies and conclude that it lies at $z \sim 1.5$. Although its colors are consistent with both an elliptical galaxy and an S0 galaxy at that redshift, its elongated shape and exponential luminosity profile suggest the presence of an evolved stellar disk component. We rule out the possibility that these properties are strongly influenced by gravitational lensing by the foreground cluster and therefore conclude that this object is more likely to be an S0-like galaxy rather than a lensed elliptical. The H-band spectrum does not show strong H_α emission, and the star formation rate therefore appears to be very modest. The presence of such a galaxy with an apparently relaxed disk of stars at this high redshift provides a new and strong constraint on theoretical models that aim to explain the formation and evolution of galaxies.

(IV) Cluster of Galaxies: Theory and Observation

1. *Spontaneous Generation of the Magnetic Field and Suppression of the Heat Conduction in Cold Fronts.* (Okabe, Nobuhiro; Hattori, Makoto) The Astrophysical Journal, Volume 599, Issue 2, pp. 964-970. (2003)

We have determined the physical mechanism responsible for plasma instabilities, which were first found by Ramani & Laval in 1978, associated with anisotropic velocity distributions induced by a temperature gradient in which there are growing low-frequency transverse magnetic waves, even in the absence of background magnetic fields. We have shown that the physical mechanism responsible for the growth of one of the modes is identical to the Weibel instability. The nonlinear saturation level of the instability is also provided by considering the wave-particle interactions. The nonlinear evolution of the magnetic fields after the saturation is speculated on. The results are applied to the cold fronts newly discovered by the Chandra X-Ray Observatory in clusters of galaxies. We predict the existence of a magnetic field of 10 μ G tangential to the surface over the entire region of the cold front and that the heat conduction is significantly suppressed by the trapping of electrons by the generated magnetic fields. The instability may provide a new possibility for the origin of the cosmic magnetic field.

2. *Chandra Analysis and Mass Estimation of the Lensing Cluster of Galaxies Cl 0024+17.* Ota, Naomi; Pointecouteau, Etienne; Hattori, Makoto; Mitsuda, Kazuhisa The Astrophysical Journal, Volume 601, Issue 1, pp. 120-132. (2004)

We present a detailed analysis of Chandra X-ray observations of the lensing cluster of galaxies Cl 0024+17 at z=0.395. We found that the radial temperature profile is consistent with being isothermal out to 600 kpc and

that the average X-ray temperature is 4.47+0.83-0.54 keV. The X-ray surface brightness profile is represented by the sum of extended emission centered at the central bright elliptical galaxy with a small core of 50 kpc and more extended emission that can be well described by a spherical β-model with a core radius of about 210 kpc. Assuming the X-ray-emitting gas to be in hydrostatic equilibrium, we estimated the X-ray mass within the arc radius and found that it is significantly smaller than the strong lensing mass by a factor of about 2-3. We detected a strong redshifted iron K line in the X-ray spectrum from the cluster for the first time and found the metal abundance to be 0.76+0.37-0.31 solar.

3. *Exploring Cluster Physics with High-Resolution Sunyaev–Zel'dovich Effect Images and X-Ray Data: The Case of the Most X-Ray-Luminous Galaxy Cluster RX J1347-1145.* Kitayama, Tetsu; Komatsu, Eiichiro; Ota, Naomi; Kuwabara, Takeshi; Suto, Yasushi; Yoshikawa, Kohji; Hattori, Makoto; Matsuo, Hiroshi Publications of the Astronomical Society of Japan, Vol.56, No.1, pp. 17-28 (2004)

Foreseeing the era of high spatial resolution measurements of the Sunyaev-Zel'dovich effect (SZE) in clusters of galaxies, we present a prototype analysis of this sort combined with Chandra X-ray data. It is applied specifically to RX J1347-1145 at z = 0.451, the most X-ray-luminous galaxy cluster known, for which the highest resolution SZE and X-ray images are currently available. We demonstrate that the combined analysis yields a unique probe of complex structures in the intracluster medium, offering determinations of their temperature, density, and line-of-sight extent. For a subclump in RX J1347-1145, previously discovered in our SZE map, the temperature inferred after removing the foreground and background components is well in excess of 20keV, indicating that the cluster has recently undergone a violent merger. Excluding the region around this subclump, the SZE signals in submillimeter to centimeter bands (350, 150, and 21GHz) are all consistent with those expected from Chandra X-ray observations. We further present a temperature deprojection technique based on the SZE and X-ray images, without any knowledge of spatially resolved X-ray spectroscopy. The methodology presented here will be applicable to a statistical sample of clusters available in the future SZE surveys.

4.*The Hα Luminosity Function of the Galaxy Cluster A521 at $z = 0.25$.* Umeda, Kazuyoshi; Yagi, Masafumi; Yamada, Sanae F.; Taniguchi, Yoshiaki; Shioya, Yasuhiro; Murayama, Takashi; Nagao, Tohru; Ajiki, Masaru; Fujita, Shinobu S.; Komiyama, Yutaka; Okamura, Sadanori; Shimasaku, Kazuhiro, 2004, ApJ, 601, 805-812

We present an optical multicolor-imaging study of the galaxy cluster A521 at $z = 0.25$, using Suprime-Cam on the Subaru Telescope, covering an area of 32 $\times$20 arcmin. Our imaging data taken with both a narrowband filter, NB816, nd broadband filters, B, V, R, i', and z', allow us to find 165 Hα emitters. We obtain the Hα luminosity function (LF) for the cluster galaxies within 2 Mpc. Although the faint-end slope is consistent with that of the local cluster Hα LFs, the characteristic luminosity L^* is about 6 times (or 2 mag) brighter. This strong evolution implies that A521 contains more active star-forming galaxies than the local clusters, being consistent with the observed Butcher-Oemler effect.

(V) General Relativity

1. *Numerical analysis of quasinormal modes in nearly extremal Schwarzschild de Sitter spacetimes.* Yoshida, Shijun; Futamase, Toshifumi Physical Review D, vol. 69, Issue 6, id. 064025 (PhRvD Homepage)

We calculate high-order quasinormal modes with large imaginary frequencies for electromagnetic and gravitational perturbations in nearly extremal Schwarzschild de Sitter spacetimes. Our results show that for low-order quasinormal modes the analytical approximation formula in the extremal limit derived by Cardoso and Lemos is quite a good approximation for the quasinormal frequencies as long as the model parameter r1 κ 1 is small enough, where r1 and κ 1 are the black hole horizon radius and the surface gravity, respectively. For high-order quasinormal modes, to which correspond quasinormal frequencies with large imaginary parts, on the other hand, this formula becomes inaccurate even for small values of r1 κ 1. We also find that the real parts of the quasinormal frequencies have oscillating behaviors in the limit of highly damped modes, which are similar to those observed in the case of a Reissner-Nordstrom black hole. The amplitude of oscillating Re(ω) as a function of Im(ω) approaches a nonzero constant value for gravitational perturbations and zero for electromagnetic perturbations in the limit of highly damped modes, where ω denotes the quasinormal frequency. This means that for gravitational perturbations the real part of the quasinormal modes of the nearly extremal Schwarzschild de Sitter spacetime appears not to approach any constant value in the limit of highly damped modes. On the other hand, for electromagnetic perturbations, the real part of the frequency seems to go to zero in the limit.

2. *New derivation of a third post-Newtonian equation of motion for relativistic compact binaries without ambiguity* Itoh, Yousuke; Futamase, Toshifumi Physical Review D, vol. 68, Issue 12, id. 121501 (PhRvD Homepage)

A third post-Newtonian (3PN) equation of motion for an inspiraling binary consisting of two spherical compact stars with strong internal gravity is derived under the harmonic coordinate condition using the strong field point particle limit. The equation of motion is complete in the sense that it is Lorentz invariant in the post-Newtonian perturbative sense, admits the conserved energy of the orbital motion, and is unambiguous, that is, with no undetermined coefficient. In this paper, we show explicit expressions of the 3PN equation of motion and an energy of the binary orbital motion in the case of a circular orbit (neglecting the 2.5PN radiation reaction effect) and in the center of mass frame. It is argued that the 3PN equation of motion we obtained is physically unambiguous.

Doctor Theses

D1) Masaru Kajisawa: *Galaxy Evolution over the Hubble Time: Color, Morphology, Mass Distribution of Galaxies in the Hubble Deep Field North.*

D2) Tohru Nagao: *Stratified Structure of Narrow-Line Regions in Active Galactic Nuclei.*

D3) Izumi Ota: *Development of Astronomical Interfero-meter Applying Fourier Transform Spectroscopy to Aperture Synthesis System in mm and sub-mm Band.*

Master Theses

M1) Toshinari Cho: *A Study of a Mira Type Variable R Trianguli Based on Low -Dispersion Polarimetory.*

M2) Kenichi Honma: *The Circumstellar Structure of β Lyr Derived from a Analysis of Polarized Emission-Line Profile.*

M3) Kyojiro Kawaguchi: *Stellar and Gas Dynamics of Flocculent Spiral Galaxies.*

M4) Masahiro Konishi: *Morphological evolution of galaxies in the Subaru deep field.*

M5) Masahiro Mizuta: *An Application of mm and sub-mm Multi Fourier Interferometer to Astronomical Observation.*

M6) Kenji Ozawa: *An Approach to Explore the Interstellar Medium Using High-precision Polarimetory and IUE Data.*

M7) Takashi Suzuki: *The Hawking Radiation and Information Paradox.*

M8) Daishi Watanabe: *An Application of a Magetized Accretion disk of Low Radiation Efficiency to Dark Galactic Nuclei.*

M9) Kazuyoshi Umeda: *An H α Imaging Survey of Two z∼0.24 Galaxy Clusters Abell 521 and Abell 708.*

M10) Sanae Yamada: *An Intermediate-Band Imaging Survey for High-z Ly α Emitters : The MAHOROBA − 7.*

M11) Tomoyuki Yasukawa: *A Survey of High Redshift Low Luminous Qasars Using Subaru Suprime-Cam.*